Effect of Asian currency crisis on multifractal spectra

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Abstract

We analyze the multifractal spectra of daily foreign exchange rates for Japan, Hong Kong, Korea, and Thailand with respect to the United States Dollar from 1991 to 2005. We find that the return time series show multifractal features for all four cases. To observe the effect of the Asian currency crisis, we compare the multifractal spectra of limited series before and after the crisis. We find that the Korean and Thai foreign exchange markets experienced a significant increase in multifractality compared to Hong Kong and Japan. We also show that the multifractality is strongly related to the presence of high return values.

I. INTRODUCTION

Economic systems are widely acknowledged as extremely complex, and have recently become an interesting area of study for physicists as well as economists [1]. Many previous studies have found that time series of financial markets exhibit some non-linear properties using methods developed in statistical physics [2, 3]. The prices in financial markets are created by non-trivial interactions among heterogeneity agents and complex events occurring in the external environment. In other words, both micro and macro variables with various time scales are involved in the pricing mechanism.

The properties observed in financial time series include long-memory in volatility [2], fat tails [3], and a multifractal nature [4, 5, 6, 7, 8] among others; these are sometimes referred to as the *stylized facts*. The multifractal concept, which is now well developed in the fields of statistical physics and nonlinear dynamics, is a well-known feature of complex systems [6, 7, 8, 9, 10, 11]. Multifractality has been discovered in systems as diverse as earthquakes [6], biological time series [7], as well as financial markets [4, 11].

Previous studies have found evidence for a relationship between the complexity of a system and its degree of multifractality [7]. For example, the degree of multifractality in data generated by a multiplicative cascading process is directly related to the long-range correlations of the magnitude time series [12]. Other factors that could affect the multifractality of time series include time correlations and the probability distribution of the data [10, 11]. However, it is still not clear what is the origin of multifractality in financial markets.

In this paper we study the multifractal properties of a financial time series: the daily return of foreign exchange (FX) markets. We consider Japan (JPY/USD), Hong Kong (HKD/USD), Korea (KRW/USD), and Thailand (THD/USD) from 1991 to 2005. We employ multifractal detrended fluctuation analysis (MF-DFA) [13] to measure the nonlinear features of the time series, in particular their multifractal spectra. To test their significance we randomly shuffle the series to remove any temporal correlations, and find that these spectra narrow significantly. In other words, we find that temporal correlation plays an important role in the multifractality of the data, similar to Matia *et al.* [10].

To detect changes in market complexity before and after the Asian currency crisis, we divide the series into two periods, before and after the crash, and calculate their multifractal spectra separately. We find that for Korea and Thailand the degree of multifractality

increased significantly after the crisis, while the FX markets of Hong Kong and Japan did not. We therefore suggest that both Korea and Thailand have been more influenced by the Asian currency crisis. We also examine the effect of return values above a certain threshold on the market complexity. We find that for all four countries, market complexity is reduced when high returns are removed.

II.   DATA AND METHODOLOGY

We investigate the multifractal properties of Asian FX markets from 1991 to 2005 for four countries: Japan (JPY/USD), Hong Kong (HKD/USD), Korea (KRW/USD), and Thailand (THB/USD). The data are obtained from http://www.federalreserve.gov/RELEASES/. In all data sets used in this paper, we remove the year 1997 to eliminate any abnormalities due to the market crash itself. The return time series is calculated by the log-difference of daily prices: $r(t) = \ln P(t) - \ln P(t-1)$, where $P(t)$ is the foreign exchange rate on day t. We divide the entire series into two sub-periods: DATA A from 1991 to 1996 (before the crisis) and DATA B from 1998 to 2005 (after the crisis). This allows us to study the influence of the Asian currency crisis on the market complexity. We employ the multifractal detrended fluctuation analysis (MF-DFA) method to determine the multifractal properties of the time series. The MF-DFA method was developed by Kantelhardt $et\ al.$ [13], and can be explained by the following three steps.

Step (1): We subtract the average value of the time series from each record $x(i)(\equiv r(t))$, then accumulate the series:

$$y(i) = \sum_{k=1}^{i} [x(k) - \bar{x}], \tag{1}$$

where $x(k)$ is the kth point of the time series and $\bar{x}$ is their average.

Step (2): The profile $y(i)$ is divided into N_s boxes of length s. In a given box $v(1 \leq v \leq N_s)$, the trend is estimated by an m-order polynomial using the least-squares method. The best-fit curve is expressed as $y_v(i)$. By subtracting $y_v(i)$ from $y(i)$, possible trends are removed [14]. This process is applied to every box, and the fluctuations in that box are then calculated as

$$F_2(s, v) \equiv \frac{1}{s} \sum_{i=1}^{s} (|y((v-1)s+i) - y_v(i)|)^2. \tag{2}$$

Step (3): We compute the q-order moment $F_q(s)$ of the series by averaging the appropriate function of F_q over all boxes. Then we obtain a scaling relation with box size s:

$$F_q(s) \equiv \{\frac{1}{N_s} \sum_{v=1}^{N_s} F_2(s, v)^{q/2}\}^{1/q} \sim s^{h(q)}. \tag{3}$$

The exponent $h(q)$ depends on q. In general, the multifractal (MF) scaling exponent $\tau(q)$ is related to $h(q)$ through

$$\tau(q) = qh(q) - D_f, \tag{4}$$

where D_f is the fractal dimension of a geometric object. In our case, $D_f = 1$. The MF exponent $\tau(q)$ represents the temporal structure of the time series as a function of the various moments q. That is, τ reflects the scale-dependence of *smaller* fluctuations for *negative* values of q, and larger fluctuations for positive values of q. In the special case that $\tau(q) = \alpha q$ is a linear function, the time series can be regarded as monofractal and α is the singularity strength or the Hölder exponent [4, 5, 6, 7, 8]. If $\tau(q)$ increases nonlinear with q, then the series is multifractal. In this case we can calculate the MF spectrum, $f(\alpha)$, by a Legendre transform of $\tau(q)$, as defined by

$$f(\alpha) \equiv \alpha q - \tau(q), \quad \alpha \equiv \frac{d\tau(q)}{dq}, \tag{5}$$

where $f(\alpha)$ is the dimension of the time series. If the time series is monofractal, $f(\alpha)$ is a delta function, there is only one value of α; otherwise, there is a distribution of α values.

III. RESULTS

We have analyzed the multifractal spectra of the Asian FX markets using the above MF-DFA method. The pricing mechanisms may well be complex due to the Asian currency crisis in 1997 as well as due to various internal and external events. The Asian currency crisis had an impact on almost all Asian FX markets [15]. Here, we study the multifractal properties of four markets and try to identify how the crisis may have affected their multifractality.

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In Fig. 1, we show the return time series of Hong Kong, Japan, Korea, and Thailand. The Korean and Thai FX markets clearly have higher volatility after the Asian currency crisis in 1997, but the Japanese and Hong Kong markets show no obvious change.

The question we pose: Is it only the values of volatilities change after the crisis or also the nonlinear properties? The test this question we analyzed the multifractal properties of these four markets. The results of MF-DFA analysis for the whole period are presented in Fig. 2. To test how significant is the multifractality, we also perform the analysis on surrogate time series created by randomly shuffling the data. Figs. 2a and b display the multifractal scaling function $\tau(q)$ of the original and shuffled data. We calculated $\tau(q)$ from the power-law relation between $F_q(s)$ and s, using scales in the range $40 < s < 600$. This is since below $s = 40$ there exist discreteness effects in both original and surrogate data. We find that the two datasets behave almost linear with q for negative moments, but show significant non-linearities for positive moments. This means that the temporal structure of the larger fluctuations have changed dramatically in the surrogate series.

To explicitly observe the multifractality we can convert q and $\tau(q)$ to α and $f(\alpha)$ by a Legendre transform. Fig. 2c shows the multifractal spectra $f(\alpha)$ of the original data. We find that the singularity strengths α of the markets lie within the following ranges: $-0.04 \leq \alpha_{\text{HongKong}} \leq 1.10$, $0.34 \leq \alpha_{\text{Japan}} \leq 0.63$, $0.29 \leq \alpha_{\text{Korea}} \leq 0.85$, and $0.08 \leq \alpha_{\text{Thailand}} \leq 0.92$. Fig. 2d presents the same information for the surrogate data: $0.18 \leq \alpha_{\text{HongKong(surrogate)}} \leq 0.73$, $0.46 \leq \alpha_{\text{Japan(surrogate)}} \leq 0.61$, $0.43 \leq \alpha_{\text{Korea(surrogate)}} \leq 0.64$, and $0.39 \leq \alpha_{\text{Thailand(surrogate)}} \leq 0.67$. Figs. 2c and d show that the multifractal spectra $f(\alpha)$ are narrower for the surrogate time series, from which all temporal correlations have been removed. Our results indicate that the correlations in Asian FX markets show signature of multifractality.

The Asian currency crisis had an influence on almost all the Asian markets, so it is reasonable to assume that their status may changed significantly. An interesting question is how the Asian currency crisis influenced the market complexity. We divided each time series into two sub-periods: (DATA A) and (DATA B) before and after the crisis respectively. Fig. 3 shows the multifractal spectra $f(\alpha)$ of the original and surrogate time series of both periods for all four markets. We find that the multifractal spectra of all the surrogate data set is reduced significantly than those of the original data. The Hong Kong and Japanese markets show a similar degree of multifractality before and after the crisis, while the Korean and

Thai markets change significantly and the multifractal spectra become broader. In other words, the complexity of the Korean and Thai markets significantly increased after the Asian currency crisis.

To quantify the market multifractality, we measure the degree of multifractality $\Delta\alpha$ definded as the difference of maximum and minimum α values. Table I shows the change $\Delta\alpha$ for each market. We conjecture that since the Japanese market is the most mature, it was also the least influenced by the Asian currency crisis. The emerging markets as Korea and Thailand, on the other hand, were greatly influenced by the crash. As for the Hong Kong market which has a fixed exchange rate with the U.S. dollar (called the Peg system), both periods have similar broad spectra. The Asian currency crisis thus increased the complexity of the Korean and Thai markets, because its aftermath spurred the development of new government policies in those countries.

We have observed that temporal correlations are not linear but posses multifractality in the time series. It is interesting to note that the surrogate time series removed the time correlation still show some multifractality. It is widely accepted that the distribution of returns in a financial market follows a power law, with an exponent close to 3 [3]. In other words, there are many higher values that cannot be predicted by the pricing mechanism of the efficiency market hypothesis (EMH) [16], which is also widely used in the financial literature. We will now investigate the influence of high returns on the multifractality. We create a new version of each time series by eliminating values above a certain threshold in units of the standard deviation of the time series. The eliminated data points are replaced by linear interpolation. As the threshold increases, the time series will retain higher values.

Fig. 4 represents the dependence of $\Delta\alpha$ on the threshold for original and surrogate data. We find that in all four countries, the FX market complexity is related to the presence of very high return values. However, the results for the surrogate data is independent of the threshold. Market value is created by non-trivial interactions between heterogeneity agents and influenced by the internal and external events. The results of Fig. 4 suggest that more complex markets are more likely to produce high returns.

IV.   CONCLUSIONS

We investigated the properties of time series from four Asian FX markets, and found two factors affecting their multifractality as measured by the MF-DFA method. First, we found that temporal correlations in the data contribute to the multifractality of all four FX markets. Second, we found that market complexity and multifractality are positively related to the presence of high return values in the series.

To observe how the Asian currency crisis influenced these FX markets, we studied their multifractal properties before and after the crisis. We found that for both Korea and Thailand, the degree of multifractality significantly increased after the crisis. Japan and Hong Kong, however, were almost unaffected. We argue that the market crash affected Korea and Thailand more strongly because they are typical emerging markets. These countries probably introduced new policies (and thus additional complexities) to help control the aftermath. However, the Japanese market is a representative mature market in Asia while Hong Kong uses an almost fixed exchange rate, the Peg system.

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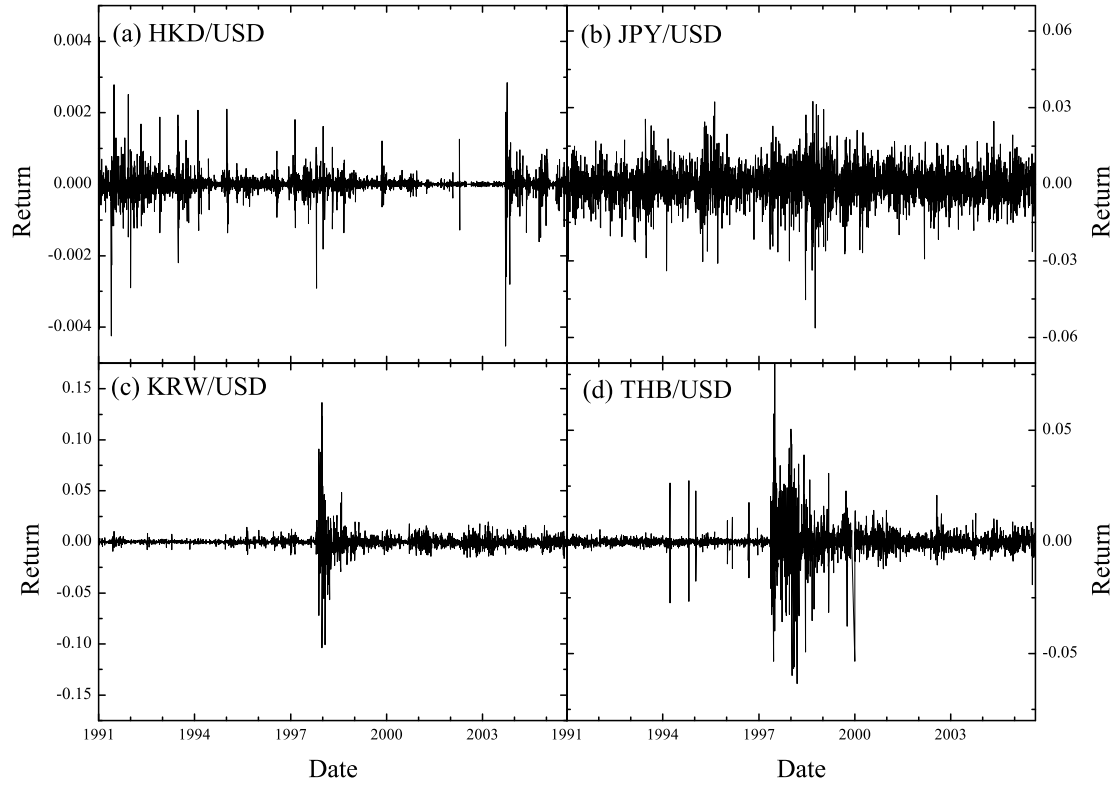[16] E. F. Fama, J. Finance **25**, 383 (1970).

FIG. 1: Returns $x(i)$ of four Asian foreign exchange markets: (a) Hong Kong, (b) Japan, (c) Korea, and (d) Thailand.
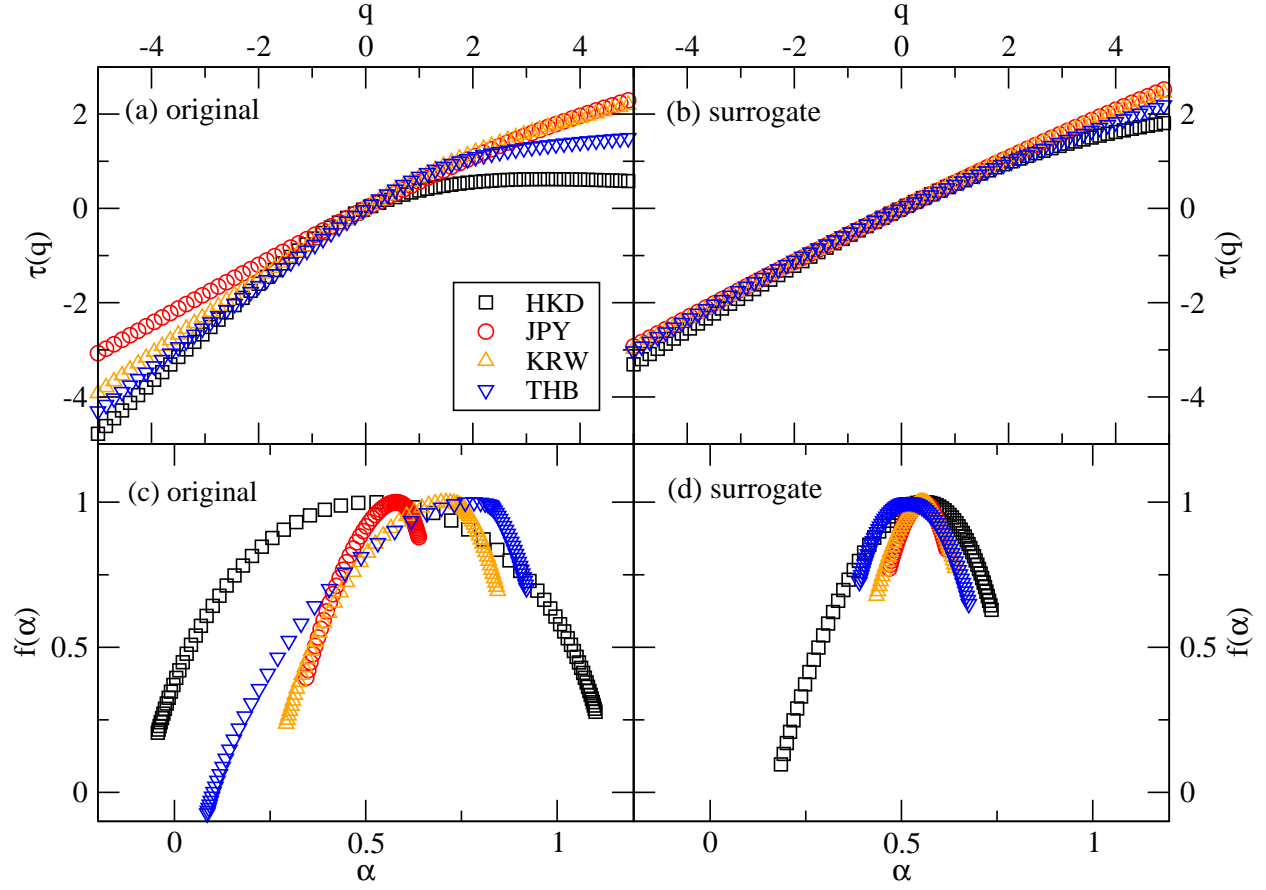
FIG. 2: (Color online). Panels (a) and (b) show the multifractal scaling exponents $\tau(q)$ of the return and surrogate time series for four foreign exchange markets. Panels (c) and (d) show the fractal dimension $f(\alpha)$ obtained by a Legendre transformation of (a) and (b) respectively.
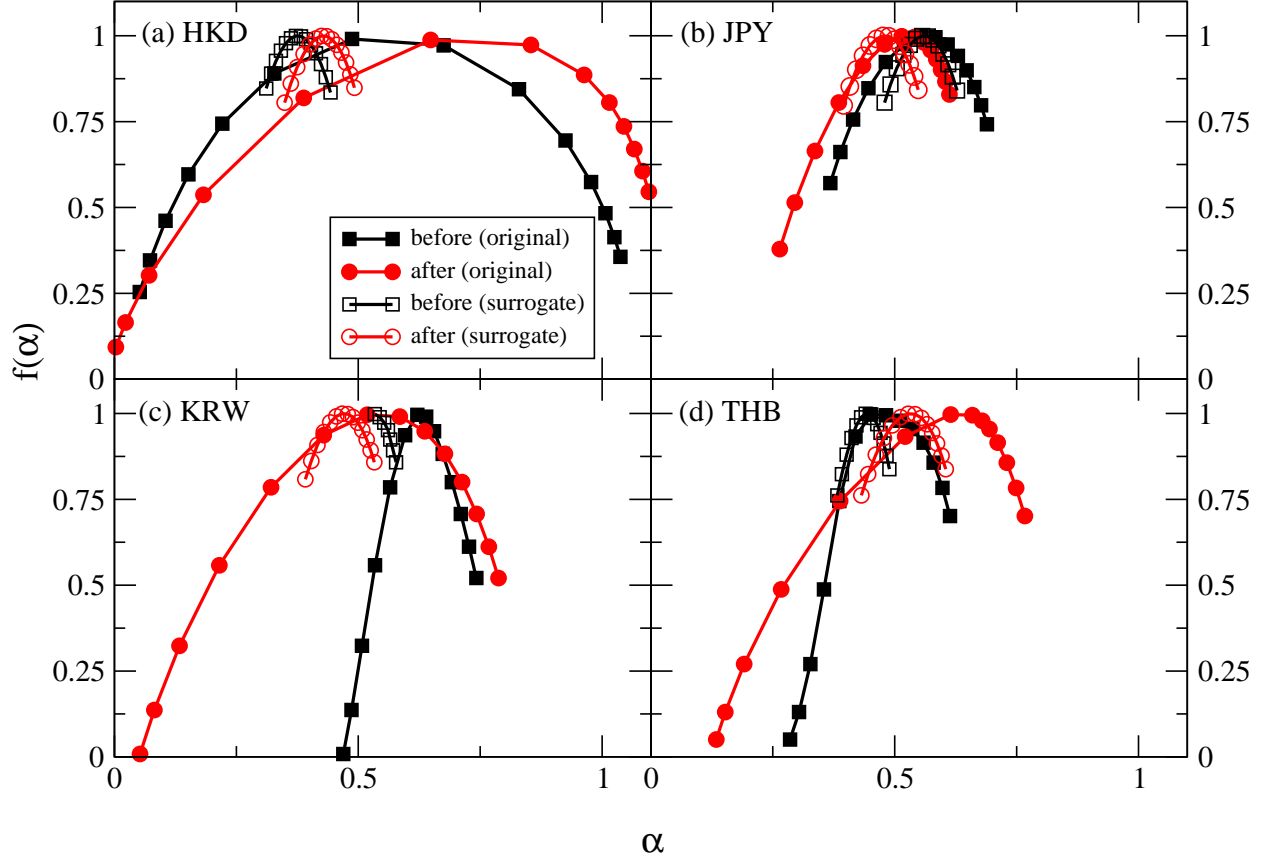
FIG. 3: (Color online). The multifractality spectrum $f(\alpha)$ before (squares) and after (circles) the Asian currency crisis for the original (closed symbols) and surrogate (open symbols) time series.
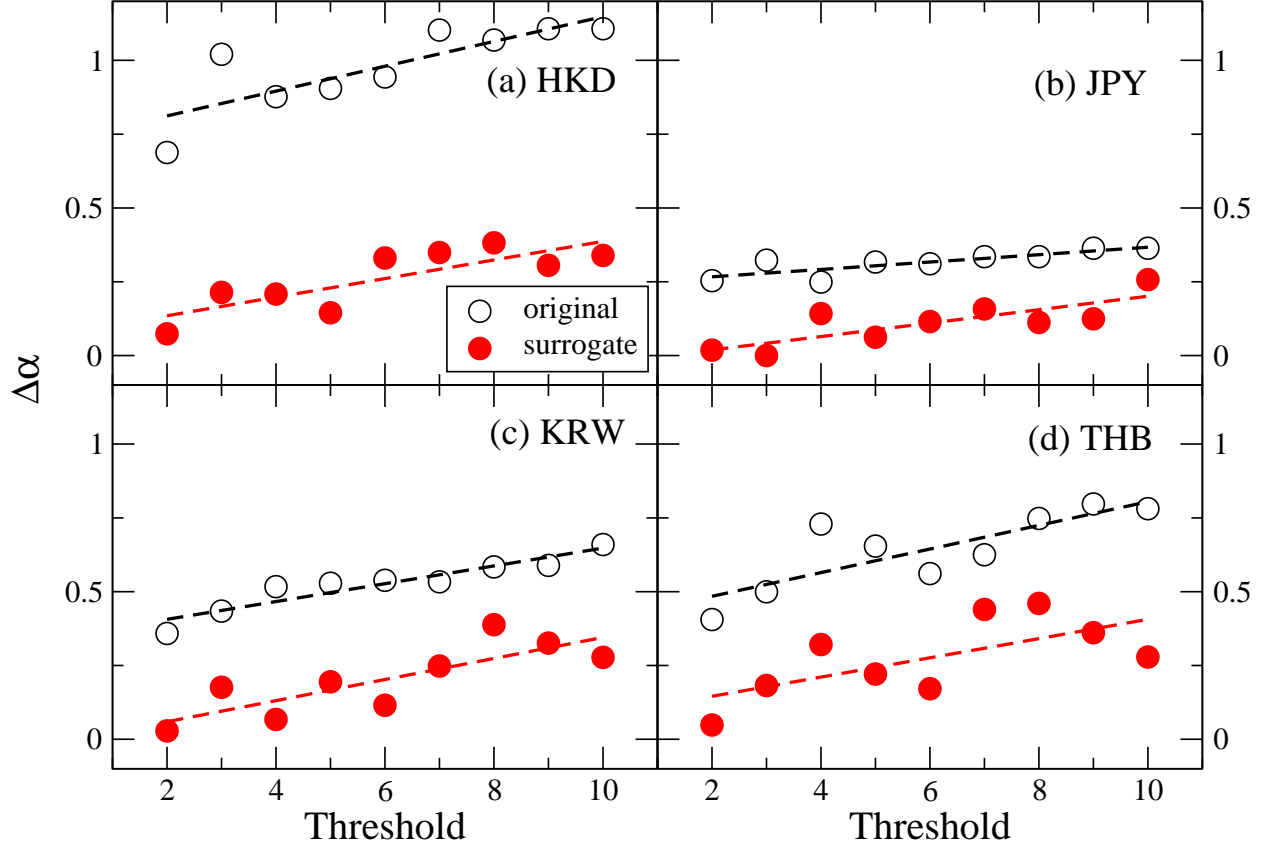
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FIG. 4: (Color online). The multifractality of time series from which returns above a threshold have been deleted and interpolated. The solid and dashed lines indicate the original and surrogate time series respectively.

TABLE I: The degree of multifractality $\Delta\alpha$ for all the countries. $\Delta\alpha_a$ represents the α value *after* the crisis, $\Delta\alpha_b$ the value *before* the crisis, $\Delta\alpha_s$ the value of the *surrogate (shuffled)* data, and $\Delta\alpha_o$ the value of the *original* data.

Country	$\Delta\alpha_a - \Delta\alpha_b$	$\Delta\alpha_o - \Delta\alpha_s$	$\Delta\alpha_a - \Delta\alpha_s$	$\Delta\alpha_b - \Delta\alpha_s$
Hong Kong	**0.11**	0.59	0.54	0.43
Japan	**0.02**	0.14	0.19	0.17
Korea	**0.46**	0.35	0.53	0.07
Thailand	**0.31**	0.55	0.35	0.04